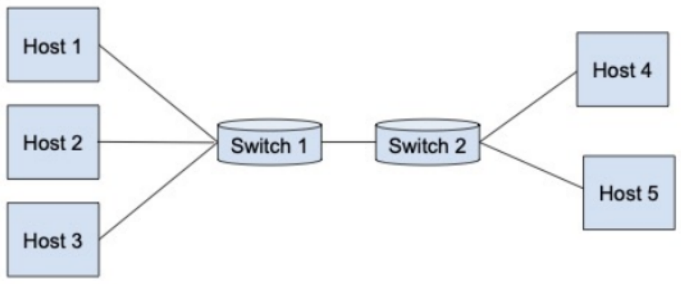
ASSIGNMENT 03

Answers to all the questions are based on the below custom topology



Custom Topology

1.

- Hub Controller

  The following is the output for the Dumb Hub Controller
  A simple hub controller forwards packets to all its ports except the incoming one without learning routes. Consequently, it lacks knowledge of past communications, resulting in flooding all ports when it receives requests from the same or new hosts. This behavior leads to consistent and similar response times when conducting multiple pings.And this is what can be verified from the results highlighted below.

#Controller_hub

```
root@mininet-vm:/home/mininet/A3# python3 topo.py
mininet> h2 ping -c 3 h5
PING 10.0.0.5 (10.0.0.5) 56(84) bytes of data.
64 bytes from 10.0.0.5: icmp_seq=1 ttl=64 time= 25.7 ms
64 bytes from 10.0.0.5: icmp_seq=2 ttl=64 time= 7.53 ms
64 bytes from 10.0.0.5: icmp_seq=3 ttl=64 time= 8.01 ms
--- 10.0.0.5 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2005ms
rtt min/avg/max/mdev = 7.527/13.758/25.738/8.472 ms

root@mininet-vm:/home/mininet/A3# ryu-manager controller_hub.py
loading app controller_hub.py
loading app ryu.controller.ofp_handler
instantiating app controller_hub.py of LearningSwitch
instantiating app ryu.controller.ofp_handler of OFPHandler
packet in 1 00:00:00:00:00:02 ff:ff:ff:ff:ff:ff 2
packet in 2 00:00:00:00:00:02 ff:ff:ff:ff:ff:ff 3
packet in 2 00:00:00:00:00:05 00:00:00:00:00:02 2
packet in 1 00:00:00:00:00:05 00:00:00:00:00:02 4
packet in 1 00:00:00:00:00:02 00:00:00:00:00:05 2
packet in 2 00:00:00:00:00:02 00:00:00:00:00:05 3
packet in 2 00:00:00:00:00:05 00:00:00:00:00:02 2
packet in 1 00:00:00:00:00:05 00:00:00:00:00:02 4
packet in 1 00:00:00:00:00:02 00:00:00:00:00:05 2
packet in 2 00:00:00:00:00:02 00:00:00:00:00:05 3
packet in 2 00:00:00:00:00:05 00:00:00:00:00:02 2
packet in 1 00:00:00:00:00:05 00:00:00:00:00:02 4
packet in 1 00:00:00:00:00:02 00:00:00:00:00:05 2
packet in 2 00:00:00:00:00:02 00:00:00:00:00:05 3
packet in 2 00:00:00:00:00:05 00:00:00:00:00:02 2
packet in 1 00:00:00:00:00:05 00:00:00:00:00:02 4
packet in 2 00:00:00:00:00:05 00:00:00:00:00:02 2
packet in 1 00:00:00:00:00:05 00:00:00:00:00:02 4
packet in 1 00:00:00:00:00:02 00:00:00:00:00:05 2
packet in 2 00:00:00:00:00:02 00:00:00:00:00:05 3
```

- Leaning Switch

  The learning switch operates by observing past network traffic and subsequently constructing a forwarding table based on these observations. This table enables the switch to efficiently handle incoming requests. When a request for a specific destination is received, the switch checks its forwarding table to determine if it has prior knowledge of the destination. If it does, it directly forwards the packet to the appropriate port. If not, it resorts to a flood mode, broadcasting the packet to all outgoing ports.
  This learning mechanism results in expedited processing for subsequent packets destined for the same location that the switch has previously encountered. This efficiency can be corroborated by analyzing the recorded results. For instance, the initial request may take 26.3 milliseconds to process, while subsequent requests show significantly reduced processing times, such as 0.415 milliseconds and 0.152 milliseconds for the second and third requests, respectively. This demonstrates the switch's ability to remember and respond faster to destinations it has encountered in the past.

```
root@mininet-vm:/home/mininet/A3# python3 topo.py
mininet> h2 ping -c 3 h5
PING 10.0.0.5 (10.0.0.5) 56(84) bytes of data.
64 bytes from 10.0.0.5: icmp_seq=1 ttl=64 time=26.3 ms
64 bytes from 10.0.0.5: icmp_seq=2 ttl=64 time=0.415 ms
64 bytes from 10.0.0.5: icmp_seq=3 ttl=64 time=0.152 ms
--- 10.0.0.5 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2007ms
rtt min/avg/max/mdev = 0.152/8.950/26.285/12.257 ms

root@mininet-vm:/home/mininet/A3# ryu-manager learning_switch.py
loading app learning_switch.py
loading app ryu.controller.ofp_handler
instantiating app learning_switch.py of LearningSwitch
instantiating app ryu.controller.ofp_handler of OFPHandler
packet in 1 00:00:00:00:00:02 ff:ff:ff:ff:ff:ff 2
packet in 2 00:00:00:00:00:02 ff:ff:ff:ff:ff:ff 3
packet in 2 00:00:00:00:00:05 00:00:00:00:00:02 2
packet in 1 00:00:00:00:00:05 00:00:00:00:00:02 4
packet in 1 00:00:00:00:00:02 00:00:00:00:00:05 2
packet in 2 00:00:00:00:00:02 00:00:00:00:00:05 3
```

- Difference between Hub Controller and Learning Switch

  1. Hub Controller: A hub controller, often referred to as a hub or a dumb hub, forwards incoming packets to all of its ports except the one from which the packet originated. It essentially broadcasts the packet to all connected devices, causing network congestion and inefficiency.

     Learning Switch: A learning switch, also known as a switch, employs an intelligent packet forwarding mechanism. It learns from past network traffic and builds a forwarding table that associates MAC addresses with the corresponding switch ports. When a packet arrives, it checks the forwarding table and forwards the packet only to the port where the destination MAC address is located, significantly reducing network traffic and enhancing efficiency.

  2. Hub Controller: A hub controller does not possess any learning capabilities. It forwards packets indiscriminately to all ports without any knowledge of the devices connected or their MAC addresses.

     Learning Switch: A learning switch actively learns the MAC addresses of devices connected to its ports. It records this information in its forwarding table, allowing it to make informed decisions about packet forwarding, based on destination MAC addresses.

1.2 Throughput

- Controller hub

```
root@mininet-vm:/home/mininet# iperf -s
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  6] local 10.0.0.1 port 5001 connected with 10.0.0.5 port 53814
[ ID] Interval       Transfer     Bandwidth
[  6]  0.0-13.2 sec  7.12 MBytes  4.53 Mbits/sec

root@mininet-vm:/home/mininet# iperf -c 10.0.0.1
------------------------------------------------------------
```

```
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  5] local 10.0.0.5 port 53814 connected with 10.0.0.1 port 5001
[ ID] Interval       Transfer     Bandwidth
[  5]  0.0-10.3 sec  7.12 MBytes  5.80 Mbits/sec
root@mininet-vm:/home/mininet#
```

- Learning switch

```
root@mininet-vm:/home/mininet# iperf -s
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  6] local 10.0.0.1 port 5001 connected with 10.0.0.5 port 53830
[ ID] Interval       Transfer     Bandwidth
[  6]  0.0-10.0 sec  26.0 GBytes  22.3 Gbits/sec

root@mininet-vm:/home/mininet# iperf -c 10.0.0.1
------------------------------------------------------------
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  5] local 10.0.0.5 port 53830 connected with 10.0.0.1 port 5001
[ ID] Interval       Transfer     Bandwidth
[  5]  0.0-10.0 sec  26.0 GBytes  22.3 Gbits/sec
root@mininet-vm:/home/mininet#
```

Here we can verify that the throughput for the learning switch is better than the controller hub due to less redundant flooding messages as the learning switch maintains the forwarding table.

1.3 The following are the installed rules on switches S1 and S2

- Controller_hub : This is dumb switch and does not store any information and can be verified from the below output.

```
root@mininet-vm:/home/mininet/A3# python3 topo.py
mininet> pingall
*** Ping: testing ping reachability
h1 -> h2 h3 h4 h5
h2 -> h1 h3 h4 h5
h3 -> h1 h2 h4 h5
```

```
h4 -> h1 h2 h3 h5
h5 -> h1 h2 h3 h4
*** Results: 0% dropped (20/20 received)
mininet> dpctl dump-flows
*** s1 ------------------------------------------------------------------------
  cookie=0x0, duration=27.278s, table=0, n_packets=80, n_bytes=5600, priority=0
actions=CONTROLLER:65535
*** s2 ------------------------------------------------------------------------
  cookie=0x0, duration=27.287s, table=0, n_packets=80, n_bytes=5600, priority=0
actions=CONTROLLER:65535
```

- Learning switch : Store rules in the forwarding tables.

```
root@mininet-vm:/home/mininet/A3# python3 topo.py
mininet> pingall
*** Ping: testing ping reachability
h1 -> h2 h3 h4 h5
h2 -> h1 h3 h4 h5
h3 -> h1 h2 h4 h5
h4 -> h1 h2 h3 h5
h5 -> h1 h2 h3 h4
*** Results: 0% dropped (20/20 received)
mininet> dpctl dump-flows
*** s1 ------------------------------------------------------------------------
     cookie=0x0, duration=7.748s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth2",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:01
actions=output:"s1-eth1"
     cookie=0x0, duration=7.741s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth1",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:02
actions=output:"s1-eth2"
     cookie=0x0, duration=7.723s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:01
actions=output:"s1-eth1"
     cookie=0x0, duration=7.717s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth1",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:03
actions=output:"s1-eth3"
     cookie=0x0, duration=7.690s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:01
actions=output:"s1-eth1"
     cookie=0x0, duration=7.688s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth1",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:04
actions=output:"s1-eth4"
     cookie=0x0, duration=7.661s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:01
actions=output:"s1-eth1"
     cookie=0x0, duration=7.657s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth1",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:05
actions=output:"s1-eth4"
     cookie=0x0, duration=7.629s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:02
actions=output:"s1-eth2"
```

```
        cookie=0x0,        duration=7.627s,        table=0,        n_packets=2,        n_bytes=140,
priority=1,in_port="s1-eth2",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:03
actions=output:"s1-eth3"
        cookie=0x0,        duration=7.600s,        table=0,        n_packets=3,        n_bytes=238,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:02
actions=output:"s1-eth2"
        cookie=0x0,        duration=7.595s,        table=0,        n_packets=2,        n_bytes=140,
priority=1,in_port="s1-eth2",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:04
actions=output:"s1-eth4"
        cookie=0x0,        duration=7.573s,        table=0,        n_packets=3,        n_bytes=238,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:02
actions=output:"s1-eth2"
        cookie=0x0,        duration=7.569s,        table=0,        n_packets=2,        n_bytes=140,
priority=1,in_port="s1-eth2",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:05
actions=output:"s1-eth4"
        cookie=0x0,        duration=7.528s,        table=0,        n_packets=3,        n_bytes=238,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:03
actions=output:"s1-eth3"
        cookie=0x0,        duration=7.523s,        table=0,        n_packets=2,        n_bytes=140,
priority=1,in_port="s1-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:04
actions=output:"s1-eth4"
        cookie=0x0,        duration=7.501s,        table=0,        n_packets=3,        n_bytes=238,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:03
actions=output:"s1-eth3"
        cookie=0x0,        duration=7.498s,        table=0,        n_packets=2,        n_bytes=140,
priority=1,in_port="s1-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:05
actions=output:"s1-eth4"
   cookie=0x0,   duration=11.146s,   table=0,   n_packets=28,   n_bytes=1680,   priority=0
actions=CONTROLLER:65535
*** s2 -------------------------------------------------------------------------
        cookie=0x0,        duration=7.703s,        table=0,        n_packets=3,        n_bytes=238,
priority=1,in_port="s2-eth1",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:01
actions=output:"s2-eth3"
        cookie=0x0,        duration=7.696s,        table=0,        n_packets=2,        n_bytes=140,
priority=1,in_port="s2-eth3",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:04
actions=output:"s2-eth1"
        cookie=0x0,        duration=7.672s,        table=0,        n_packets=3,        n_bytes=238,
priority=1,in_port="s2-eth2",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:01
actions=output:"s2-eth3"
        cookie=0x0,        duration=7.663s,        table=0,        n_packets=2,        n_bytes=140,
priority=1,in_port="s2-eth3",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:05
actions=output:"s2-eth2"
        cookie=0x0,        duration=7.617s,        table=0,        n_packets=3,        n_bytes=238,
priority=1,in_port="s2-eth1",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:02
actions=output:"s2-eth3"
        cookie=0x0,        duration=7.601s,        table=0,        n_packets=2,        n_bytes=140,
priority=1,in_port="s2-eth3",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:04
actions=output:"s2-eth1"
        cookie=0x0,        duration=7.586s,        table=0,        n_packets=3,        n_bytes=238,
priority=1,in_port="s2-eth2",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:02
actions=output:"s2-eth3"
        cookie=0x0,        duration=7.576s,        table=0,        n_packets=2,        n_bytes=140,
priority=1,in_port="s2-eth3",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:05
actions=output:"s2-eth2"
```

```
cookie=0x0, duration=7.548s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s2-eth1",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:03
actions=output:"s2-eth3"
 cookie=0x0, duration=7.530s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s2-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:04
actions=output:"s2-eth1"
 cookie=0x0, duration=7.514s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s2-eth2",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:03
actions=output:"s2-eth3"
 cookie=0x0, duration=7.504s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s2-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:05
actions=output:"s2-eth2"
 cookie=0x0, duration=7.466s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s2-eth2",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:04
actions=output:"s2-eth1"
 cookie=0x0, duration=7.457s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s2-eth1",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:05
actions=output:"s2-eth2"
 cookie=0x0, duration=11.153s, table=0, n_packets=24, n_bytes=1400, priority=0
actions=CONTROLLER:65535
```

2.1

In this context, our objective is to establish restrictions on communication between certain hosts while also monitoring incoming packets from host H3 on the switch. This can be confirmed through the results obtained when performing a 'pingall' operation, which involves sending ping requests from all hosts to all other hosts.

Specifically, we aim to prevent communication between H2 and H3, as well as between H5 and H1 with H4. These restrictions are evident in the results, where attempts to ping between these host pairs are indicated with an 'X,' signifying the inability to establish a connection. Furthermore, during this evaluation, we keep a tally of all incoming packets originating from host H3, which allows us to monitor and track the communication patterns of this particular host on the switch.

- Prevent communication between H2 and H3 with H5, and H1 with H4

```
root@mininet-vm:/home/mininet/A3# python3 topo.py
mininet> pingall
*** Ping: testing ping reachability
h1 -> h2 h3 X h5
h2 -> h1 h3 h4 X
h3 -> h1 h2 h4 X
h4 -> X h2 h3 h5
h5 -> h1 X X h4
*** Results: 30% dropped (14/20 received)
```

- Counting the packets for H3 on switch S1

```
root@mininet-vm:/home/mininet/A3# ryu-manager firewall_monitor.py
loading app firewall_monitor.py
loading app ryu.controller.ofp_handler
instantiating app firewall_monitor.py of FirewallApp
instantiating app ryu.controller.ofp_handler of OFPHandler
packet in 1 00:00:00:00:00:01 ff:ff:ff:ff:ff:ff 1
packet in 2 00:00:00:00:00:01 ff:ff:ff:ff:ff:ff 3
packet in 1 00:00:00:00:00:02 00:00:00:00:00:01 2
packet in 1 00:00:00:00:00:01 00:00:00:00:00:02 1
packet in 1 00:00:00:00:00:01 ff:ff:ff:ff:ff:ff 1
packet in 2 00:00:00:00:00:01 ff:ff:ff:ff:ff:ff 3
packet in 1 00:00:00:00:00:03 00:00:00:00:00:01 3
Packet count for h3 on switch s1: 1
packet in 1 00:00:00:00:00:01 00:00:00:00:00:03 1
packet in 1 00:00:00:00:00:01 ff:ff:ff:ff:ff:ff 1
packet in 2 00:00:00:00:00:01 ff:ff:ff:ff:ff:ff 3
packet in 2 00:00:00:00:00:04 00:00:00:00:00:01 1
packet in 1 00:00:00:00:00:04 00:00:00:00:00:01 4
packet in 1 00:00:00:00:00:01 00:00:00:00:00:04 1
packet in 1 00:00:00:00:00:01 ff:ff:ff:ff:ff:ff 1
packet in 2 00:00:00:00:00:01 ff:ff:ff:ff:ff:ff 3
packet in 2 00:00:00:00:00:05 00:00:00:00:00:01 2
packet in 1 00:00:00:00:00:05 00:00:00:00:00:01 4
packet in 1 00:00:00:00:00:01 00:00:00:00:00:05 1
packet in 2 00:00:00:00:00:01 00:00:00:00:00:05 3
packet in 1 00:00:00:00:00:02 ff:ff:ff:ff:ff:ff 2
packet in 2 00:00:00:00:00:02 ff:ff:ff:ff:ff:ff 3
packet in 1 00:00:00:00:00:03 00:00:00:00:00:02 3
Packet count for h3 on switch s1: 2
packet in 1 00:00:00:00:00:02 00:00:00:00:00:03 2
packet in 1 00:00:00:00:00:02 ff:ff:ff:ff:ff:ff 2
packet in 2 00:00:00:00:00:02 ff:ff:ff:ff:ff:ff 3
packet in 2 00:00:00:00:00:04 00:00:00:00:00:02 1
packet in 1 00:00:00:00:00:04 00:00:00:00:00:02 4
packet in 1 00:00:00:00:00:02 00:00:00:00:00:04 2
packet in 2 00:00:00:00:00:02 00:00:00:00:00:04 3
packet in 1 00:00:00:00:00:02 ff:ff:ff:ff:ff:ff 2
packet in 2 00:00:00:00:00:02 ff:ff:ff:ff:ff:ff 3
packet in 2 00:00:00:00:00:05 00:00:00:00:00:02 2
packet in 1 00:00:00:00:00:05 00:00:00:00:00:02 4
packet in 1 00:00:00:00:00:02 00:00:00:00:00:05 2
packet in 1 00:00:00:00:00:03 ff:ff:ff:ff:ff:ff 3
Packet count for h3 on switch s1: 3
packet in 2 00:00:00:00:00:03 ff:ff:ff:ff:ff:ff 3
packet in 2 00:00:00:00:00:04 00:00:00:00:00:03 1
packet in 1 00:00:00:00:00:04 00:00:00:00:00:03 4
packet in 1 00:00:00:00:00:03 00:00:00:00:00:04 3
Packet count for h3 on switch s1: 4
packet in 2 00:00:00:00:00:03 00:00:00:00:00:04 3
packet in 1 00:00:00:00:00:03 ff:ff:ff:ff:ff:ff 3
Packet count for h3 on switch s1: 5
packet in 2 00:00:00:00:00:03 ff:ff:ff:ff:ff:ff 3
packet in 2 00:00:00:00:00:05 00:00:00:00:00:03 2
packet in 1 00:00:00:00:00:05 00:00:00:00:00:03 4
packet in 1 00:00:00:00:00:03 00:00:00:00:00:05 3
packet in 1 00:00:00:00:00:01 00:00:00:00:00:04 1
packet in 1 00:00:00:00:00:01 00:00:00:00:00:04 1
packet in 1 00:00:00:00:00:01 00:00:00:00:00:04 1
packet in 1 00:00:00:00:00:01 00:00:00:00:00:04 1
packet in 2 00:00:00:00:00:04 ff:ff:ff:ff:ff:ff 1
packet in 1 00:00:00:00:00:04 ff:ff:ff:ff:ff:ff 4
packet in 2 00:00:00:00:00:05 00:00:00:00:00:04 2
packet in 2 00:00:00:00:00:04 00:00:00:00:00:05 1
packet in 1 00:00:00:00:00:02 00:00:00:00:00:05 2
packet in 1 00:00:00:00:00:02 00:00:00:00:00:05 2
packet in 1 00:00:00:00:00:02 00:00:00:00:00:05 2
packet in 1 00:00:00:00:00:02 00:00:00:00:00:05 2
packet in 1 00:00:00:00:00:03 00:00:00:00:00:05 3
packet in 1 00:00:00:00:00:03 00:00:00:00:00:05 3
packet in 1 00:00:00:00:00:03 00:00:00:00:00:05 3
packet in 1 00:00:00:00:00:03 00:00:00:00:00:05 3
```

- Installed rules on switches S1 and S2

```
mininet> dpctl dump-flows
*** s1 ------------------------------------------------------------------------
    cookie=0x0, duration=189.253s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth2",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:01
actions=output:"s1-eth1"
    cookie=0x0, duration=189.246s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth1",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:02
actions=output:"s1-eth2"
    cookie=0x0, duration=189.229s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:01
actions=output:"s1-eth1"
    cookie=0x0, duration=189.223s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth1",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:03
actions=output:"s1-eth3"
    cookie=0x0, duration=189.201s, table=0, n_packets=4, n_bytes=224,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:01
actions=output:"s1-eth1"
    cookie=0x0, duration=179.180s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:01
actions=output:"s1-eth1"
    cookie=0x0, duration=179.174s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth1",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:05
actions=output:"s1-eth4"
    cookie=0x0, duration=179.141s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:02
actions=output:"s1-eth2"
    cookie=0x0, duration=179.138s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth2",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:03
actions=output:"s1-eth3"
    cookie=0x0, duration=179.114s, table=0, n_packets=4, n_bytes=280,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:02
actions=output:"s1-eth2"
    cookie=0x0, duration=179.109s, table=0, n_packets=3, n_bytes=182,
priority=1,in_port="s1-eth2",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:04
actions=output:"s1-eth4"
```

```
    cookie=0x0, duration=179.092s, table=0, n_packets=4, n_bytes=224,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:02
actions=output:"s1-eth2"
    cookie=0x0, duration=169.064s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:03
actions=output:"s1-eth3"
    cookie=0x0, duration=169.061s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:04
actions=output:"s1-eth4"
    cookie=0x0, duration=169.034s, table=0, n_packets=4, n_bytes=224,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:03
actions=output:"s1-eth3"
  cookie=0x0, duration=192.425s, table=0, n_packets=40, n_bytes=2352, priority=0
actions=CONTROLLER:65535

*** s2 ------------------------------------------------------------------------
    cookie=0x0, duration=189.213s, table=0, n_packets=4, n_bytes=224,
priority=1,in_port="s2-eth1",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:01
actions=output:"s2-eth3"
    cookie=0x0, duration=179.198s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s2-eth2",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:01
actions=output:"s2-eth3"
    cookie=0x0, duration=179.176s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s2-eth3",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:05
actions=output:"s2-eth2"
    cookie=0x0, duration=179.133s, table=0, n_packets=4, n_bytes=280,
priority=1,in_port="s2-eth1",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:02
actions=output:"s2-eth3"
    cookie=0x0, duration=179.115s, table=0, n_packets=3, n_bytes=182,
priority=1,in_port="s2-eth3",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:04
actions=output:"s2-eth1"
    cookie=0x0, duration=179.103s, table=0, n_packets=4, n_bytes=224,
priority=1,in_port="s2-eth2",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:02
actions=output:"s2-eth3"
    cookie=0x0, duration=169.078s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s2-eth1",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:03
actions=output:"s2-eth3"
    cookie=0x0, duration=169.067s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s2-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:04
actions=output:"s2-eth1"
    cookie=0x0, duration=169.052s, table=0, n_packets=4, n_bytes=224,
priority=1,in_port="s2-eth2",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:03
actions=output:"s2-eth3"
    cookie=0x0, duration=149.012s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s2-eth2",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:04
actions=output:"s2-eth1"
    cookie=0x0, duration=149.010s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s2-eth1",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:05
actions=output:"s2-eth2"
  cookie=0x0, duration=192.431s, table=0, n_packets=21, n_bytes=1106, priority=0
actions=CONTROLLER:65535
```

2.2. Can you think of ways to minimize the number of firewall rules on the switch?

- Instead of specifying rules for individual hosts, group hosts into subnets and apply rules at the subnet level. For example, if H2, H3, and H5 are in one subnet, you can create a single rule to block communication to or from that entire subnet.
- Employ wildcard rules or wildcard masks to represent multiple IP addresses or subnets with a single rule. For instance, you can create a rule to block traffic from any IP within a specific range.
- Rather than specifying individual hosts, you can focus on blocking or allowing traffic by port or service. This is particularly useful when you want to restrict access to specific services regardless of the source or destination.

2.3. Implementing Real-Time Firewall Policies Without Interference

- Implement firewall rules in a dynamic manner, which allows for real-time updates. This involves using a controller or firewall management system that can push updates to the switches without manual intervention. The new rules will override or supplement the existing ones as needed.
- When applying real-time policies, ensure that these policies take precedence over existing rules. This can be achieved by defining rule priorities, where real-time rules have a higher priority and thus are processed before the pre-existing rules.
- Maintain version control for your firewall rules. When applying real-time policies, label them with a version number or timestamp. This way, you can easily track and manage the evolution of your rules and revert to previous versions if necessary.

3

In this section of the assignment, we were tasked with implementing a load balancer to evenly distribute the load between servers H4 and H5. To achieve this, we designed a mechanism to alternate incoming requests between these servers. Consequently, when a new packet request arrives at switch S1, it is forwarded to either host H4 or H5 in an alternating fashion, effectively distributing the load and achieving a balanced utilization of both servers.
The results presented below provide confirmation of the expected outcomes. For example, when initiating a ping request from host H1, we observe that it is initially assigned to server 10.0.0.4, and upon subsequent requests, it is directed to server 10.0.0.5. This demonstrates the load balancer's effectiveness in achieving the desired load distribution, as requests are dynamically routed to the servers in an alternating manner.

- Mininet ping to the VIRTUAL_IP(10.0.0.42)

```
root@mininet-vm:/home/mininet/A3# python3 topo.py
```

```
mininet> h1 ping -c 1 10.0.0.42
PING 10.0.0.42 (10.0.0.42) 56(84) bytes of data.
--- 10.0.0.42 ping statistics ---
1 packets transmitted, 0 received, 100% packet loss, time 0ms

mininet> h1 ping -c 1 10.0.0.42
PING 10.0.0.42 (10.0.0.42) 56(84) bytes of data.
--- 10.0.0.42 ping statistics ---
1 packets transmitted, 0 received, 100% packet loss, time 0ms

mininet> h2 ping -c 1 10.0.0.42
PING 10.0.0.42 (10.0.0.42) 56(84) bytes of data.
--- 10.0.0.42 ping statistics ---
1 packets transmitted, 0 received, 100% packet loss, time 0ms

mininet> h2 ping -c 1 10.0.0.42
PING 10.0.0.42 (10.0.0.42) 56(84) bytes of data.
--- 10.0.0.42 ping statistics ---
1 packets transmitted, 0 received, 100% packet loss, time 0ms
```

- Selected servers for requests

```
root@mininet-vm:/home/mininet/A3# nano load_balancer.py
root@mininet-vm:/home/mininet/A3# ryu-manager load_balancer.py
loading app load_balancer.py
loading app ryu.controller.ofp_handler
instantiating app load_balancer.py of SimpleSwitch13
Done with initial setup related to server list creation.
instantiating app ryu.controller.ofp_handler of OFPHandler
(((Entered the ARP Reply function to build a packet and reply back appropriately)))
{{{Exiting the ARP Reply Function as done with processing for ARP reply packet}}}
::::Sent the packet_out::::
The selected server is ===>  10.0.0.4
<========Packet from client: 10.0.0.1. Sent to server: 10.0.0.4, MAC: 00:00:00:00:00:04
and on switch port: 1========>
<++++++++Reply sent from server: 10.0.0.4, MAC: 00:00:00:00:00:04. Via load balancer:
10.0.0.42. To client: 10.0.0.1++++++++>
The selected server is ===>  10.0.0.5
<========Packet from client: 10.0.0.1. Sent to server: 10.0.0.5, MAC: 00:00:00:00:00:05
and on switch port: 2========>
<++++++++Reply sent from server: 10.0.0.5, MAC: 00:00:00:00:00:05. Via load balancer:
10.0.0.42. To client: 10.0.0.1++++++++>
(((Entered the ARP Reply function to build a packet and reply back appropriately)))
{{{Exiting the ARP Reply Function as done with processing for ARP reply packet}}}
::::Sent the packet_out::::
The selected server is ===>  10.0.0.4
<========Packet from client: 10.0.0.2. Sent to server: 10.0.0.4, MAC: 00:00:00:00:00:04
and on switch port: 1========>
<++++++++Reply sent from server: 10.0.0.4, MAC: 00:00:00:00:00:04. Via load balancer:
10.0.0.42. To client: 10.0.0.2++++++++>
The selected server is ===>  10.0.0.5
<========Packet from client: 10.0.0.2. Sent to server: 10.0.0.5, MAC: 00:00:00:00:00:05
and on switch port: 2========>
```

```
<+++++++++Reply sent from server: 10.0.0.5, MAC: 00:00:00:00:00:05. Via load balancer:
10.0.0.42. To client: 10.0.0.2++++++++>
```

- (H1, H2, and H3) ping the virtual IP and the installed rule on the switches

```
mininet> h1 ping -c 3 10.0.0.42
PING 10.0.0.42 (10.0.0.42) 56(84) bytes of data.
--- 10.0.0.42 ping statistics ---
3 packets transmitted, 100% received, 0 packet loss, time 2041ms
mininet> h2 ping -c 3 10.0.0.42
PING 10.0.0.42 (10.0.0.42) 56(84) bytes of data.
--- 10.0.0.42 ping statistics ---
3 packets transmitted, 100% received, 0 packet loss, time 2033ms
mininet> h3 ping -c 3 10.0.0.42
PING 10.0.0.42 (10.0.0.42) 56(84) bytes of data.
--- 10.0.0.42 ping statistics ---
3 packets transmitted, 100% received, 0 packet loss, time 2053ms

mininet> dpctl dump-flows
*** s1 ------------------------------------------------------------------------
  cookie=0x0, duration=279.401s, table=0, n_packets=6, n_bytes=420, priority=0
actions=CONTROLLER:65535
*** s2 ------------------------------------------------------------------------
  cookie=0x0, duration=279.407s, table=0, n_packets=0, n_bytes=0, priority=0
actions=CONTROLLER:65535
mininet>
```

3.2. If you were to implement a load balancing policy that considers the load on these servers, what additional steps would you take?

- Implement a mechanism to monitor the health and load of the servers (H4 and H5). This can involve periodically sending health checks or pings to the servers to assess their responsiveness and availability.
- Develop logic to dynamically adjust the load balancing strategy based on the current server loads. This might include collecting statistics on server response times, CPU usage, or other relevant metrics. If one server becomes overloaded or unresponsive, the load balancer should direct less traffic to it.
- Modify the load balancing algorithm to use weighted round-robin. Assign weights to each server based on their capacity or performance. For example, if H4 is more powerful than H5, it can be assigned a higher weight to receive a larger share of the traffic. This allows you to distribute the load in a way that is proportional to the servers' capabilities.